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(54) Magnetic field generating device for MRI.

(57) Disclosed is an MRI-dedicated magnetic field generating device for generating magnetic fields within an air gap, including: a pair of permanent magnet assemblies opposite to each other to form an air gap therebetween; yokes for magnetically linking the permanent magnet assemblies; and magnetic pole pieces fixed to air-gap-confronting surfaces thereof. Based on this construction, intensities of the magnetic fields are increased by disposing a plurality of magnetic material segments on the same circle or a concentric circle on the confronting surface thereof or decreased by disposing a plurality of permanent magnet segments having a magnetizing direction opposite to that of the permanent magnet assemblies on the same circle or the concentric circle on the confronting surface thereof; or alternatively both the magnetic material segments and the permanent magnet segments are disposed on the same circle or the concentric circle.

MAGNETIC FIELD GENERATING DEVICE FOR MRI

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is directed generally to an improvement of a magnetic field generating device employing permanent magnets and used for a magnetic resonance imaging device (hereinafter abbreviated to MRI) for a medical-purpose, and more particularly, to a magnetic field generating device for MRI, the arrangement being such that a plurality of magnetic field adjusting magnetic material segments and/or a plurality of magnetic field adjusting permanent magnet segments having a magnetizing direction opposite to that of permanent magnet assemblies are disposed on the same circles or concentric circles on magnetic pole piece surfaces standing vis-a-vis with an air gap to thereby eliminate a non-uniformity of the magnetic fields which is ascribed particularly to a difference in configuration between yokes in a magnetic circuit.

2. Description of the Prior Art

The medical-purpose magnetic resonance imaging device (MRI) is a tomograph capable of obtaining a sectional image of an object by inserting a part of or all of a subject to be examined into an air gap of a magnetic field generating device for generating intensive magnetic fields and depicting even properties of the tissues thereof.

The magnetic field generating device for MRI requires an air gap enough to insert a part or all of the subject. Besides, it is typically required that an intensive and uniform magnetic field exhibiting an accuracy on the order of 0.005 - 2.0T and 1×10^{-4} or less be created in an imaging visual field within the air gap.

One known arrangement of the magnetic field generating device for MRI is that magnetic pole pieces (2), (2) opposite to each other are, as illustrated in FIG. 1, fixed to one ends of a pair of permanent magnet assemblies (1), (1) which employ Fe-B-R series magnets; tabular yokes (4) and (5) are fixed to the other ends thereof and linked to each other via a four lengths of columnar yokes (6); and a static magnetic field is generated within an air gap (7) defined by the magnetic pole pieces (2), (2).

Based on the construction given above, with the intention of creating more stable and uniform magnetic field, for instance, there has been proposed a magnetic field generating device (Japanese Utility Model Laid-Open Publication No.60-166110), wherein annular projections (3) are shaped on the confronting surfaces of the magnetic pole pieces; or alternatively convex projections are formed at the centers of the confronting surfaces of the magnetic pole pieces.

On the basis of the above-described construction, there has also been proposed a magnetic field generating device (Japanese Utility Model Laid-Open Publication No.62-112106), wherein the annular projections are provided on the confronting surfaces of the magnetic pole pieces, and a single or a plurality of magnetic field adjusting pieces made of a magnetic material are secured to predetermined portions of the annular projections.

The uniformity of the magnetic field of the magnetic field generating device is, as discussed above, required to have an accuracy on the order of 1×10^{-4} within a predetermined space but is greatly influenced depending on configurations of the yokes or placement thereof in a magnetic circuit and, in particular, greatly influenced by configurations of the magnetic pole pieces.

For example, as in the case of Fig. 1, not only the configurations of the magnetic pole pieces but also the rectangular tabular yokes (4) and (5) and the columnar yokes (6) exert large influences on the uniformity of the magnetic field. The rectangular tabular yokes (4) and (5) intensity the magnetic field acting in a direction Y rather than in a direction X. whereas the columnar yokes (6) weaken the magnetic field acting in a columnar direction.

A high uniformity is obtained by providing the annular projections on the magnetic pole pieces. If an intensity of the magnetic field is locally increased on the magnetic pole piece according to the configurations and placement of the above-mentioned composing members of the magnetic field so as to provide a higher uniformity, iron pieces may be bonded thereto, as is disclosed in Japanese Utility model Laid-Open Publication No.62-112106. An extremely high uniformity can not, however, be obtained simply by bonding the iron pieces to the magnetic pole pieces.

Whereas in an attempt to locally decrease the intensity of the magnetic field, a thinkable measure is to reduce the number of magnetic pole pieces concerned disposed on the portions, i.e., to form holes. It is, however, difficult to reprocess the magnetic pole pieces such as boring after the fabrication has been performed. Desired effects are not necessarily be acquired.

SUMMARY OF THE INVENTION

It is a primary object of the present invention to provide a magnetic field generating device for MRI which is capable of locally increasing or decreasing an intensity of a magnetic field within a predetermined air gap by a predetermined quantity without reprocessing magnetic pole pieces and obtaining the magnetic field exhibiting an extremely high uniformity.

The inventors have made various studies of the magnetic field generating device which can locally increase or decrease the magnetic field intensity in a desired air gap without any requirement to rearrange the magnetic pole pieces and discovered that in accordance with the degree of the magnetic field intensity measured in the respective concentric circles which are defined by a plurality of horizontal planes traversing a spherical air gap assumed in the central portion of the air gap formed between the magnetic pole pieces, if the magnetic material segments and/or permanent magnet segments having the same magnetizing direction as that of the prmanent magnet assemblies are arranged at the predetermined portions on the surfaces of the magnetic pole pieces confronting the air gap so as to increase the magnetic field intensity and the permanent magnet segments having the magnetizing direction opposite to that of the permanent magnet assemblies are arranged at the predetermined portions on the surfaces of the magnetic pole pieces confronting the air gap so as to decrease the magnetic field intensity, the arrangements can make readily a fine adjustment of the magnetic field, thereby enabling to provide the magnetic field of a considerably high uniformity.

More precisely, the inventors have found from various experiments that the most suitable portions for a adjusting the magnetic field intensity on the circumference of the circle formed by the horizontal plane traversing the above-mentioned spherical air gap are located on the surfaces of the magnetic pole pieces confronting the air gap correspondingly to the respective circumferential portions. The magnetic field intensity on the circumference of the circle formed by horizontally traversing the spherical air gap can be adjusted by arranging the magnetic material segments and/or permanent magnet segments on the circumference of the same circle on the surface of the magnetic pole piece. Moreover, in order to equalize the average value of the magnetic field intensity on the respective circumferences of the circles formed by horizontally traversing the spherical air gap it is effective to arrange the magnetic material segments and/or permanent magnet segments concentrically on the same circle on the surface of the magnetic pole pieces.

To accomplish the above-described object, according to one aspect of the invention, there is provided an MRI-dedicated magnetic field generating device for generating magnetic fields within an air gap, comprising: a pair of permanent magnet assemblies disposed vis-a-vis with each other to form an air gap therebetween; yokes for magnetically linking the permanent magnet assemblies; and magnetic pole pieces fixed to air-gap-confronting surfaces of the permanent magnet assemblies, characterized in that intensities of the magnetic fields are increased by disposing a plurality of magnetic material segments and/or a plurality of permanent magnet segments for adjusting the magnetic field intensity and having the same magnetizing direction as that of the permanent magnet assemblies for adjusting the magnetic fields on the same circle or a concentric circle on the air-gap-confronting surface of the magnetic pole piece or decreased by disposing a plurality of magnetic field adjusting permanent magnet segments, whose magnetizing direction is opposite to that of the permanent magnet assemblies, on the same circle or the concentric circle on the air-gap-confronting surface of the magnetic pole piece; or alternatively both the magnetic field adjusting magnetic material segments and the magnetic field adjusting permanent magnet segments are disposed on the same circle or the concentric circle.

According to the present invention, a magnetic circuit may take any constructions on condition that the pair of permanent magnet assemblies disposed vis-a-vis with each other for form the air gap therebetween are magnetically linked via the yokes to each other, and the magnetic pole pieces are fixed to the air-gap-confronting surfaces of the respective permanent magnet assemblies. Preferably, the constructions are adequately selected depending on magnetic properties and configurational dimensions of the permanent magnets, configurational dimensions of the yokes and a size of the air gap required.

According to the present invention, the magnetic pole pieces are allowed to take arbitrary configurations and forms, wherein for the purpose of improving the informity of the magnetic fields the magnetic pole piece as a disk-like magnetic body may be formed with an annular projection assuming a trapezoidal or rectangular shape in section on an outer periphery thereof and with a convex projection assuming a trapezoidal shape in section at the center of the magnetic pole piece itself. In addition, adequately selectable materials for the magnetic pole piece include bulks of a variety of magnetic materials, solidified magnetic powder, a laminate assuming a concentric circle and composites of heterogeneous materials.

Usable permanent magnets of the magnet assemblies employed for the aforementioned magnetic circuit are ferrite magnets, Alnico series magnets and rare earth cobalt series magnets. In particular, there is employed a light rare earth element group which is abundant in terms of resources, wherein Nd and Pr serving as R are dominant. Used also are Fe-B-R series permanent magnets exhibiting an extremely high energy product of 30 MGOe or more with the main components being B and Fe. By virtue of using those magnets, the magnetic circuit can remarkably be miniaturized.

Configurations and dimensions of the magnetic material segments and the permanent magnet segments are properly selectable, as will be mentioned later, depending on conditions under which the magnetic fields are adjusted.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the present invention will become apparent during the following discussion taken in conjunction with the accompanying drawings, in which:

FIG 1a is a vertical sectional view of assistance in explaining a magnetic field generating device on one embodiment of the present invention; FIG. 1b is cross-sectional explanatory view thereof; FIG. 1c is a partially enlarged explanatory view of FIG. 1a; FIG. 1d to 1g are partially enlarged explanatory views, each showing other embodiment of FIG. 1c.

FIG. 2 is a perspective view, illustrating an air gap, of assistance in explaining a method of measuring a magnetic field within an air space of a spherical body of the magnetic field generating device;

FIG. 3 is a graphic chart showing measured results of the magnetic fields on axes X, Y and Z within the air space of the spherical body, the results being expressed by azimuths and magnetic field intensities;

FIG. 4 is a graphic chart showing the measured results of the magnetic fields on the axes X, Y and Z within the air gap of the spherical body in the magnetic field generating device before employing magnetic pole pieces according to the present invention which is shown in FIG. 1, the results being expressed by the azimuths and the magnetic field intensities;

FIG. 5 is a graphic chart similarly showing the measured results of the magnetic fields on circumferences of horizontal planes Pa through Pg, which are expressed by the azimuths and the magnetic field intensities; and

FIG. 6 is a graphic chart similarly showing the measured results of the magnetic fields on the circumferences of the horizontal planes Pa through Pg depicted in FIG. 2, which are expressed by the azimuths and the magnetic field intensities.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1a is a vertical sectional explanatory view of a magnetic field generating device, showing one embodiment of the present invention. FIG. 1b is a cross-sectional explanatory view thereof. FIG. 1c is a partially enlarged explanatory view of FIG. 1a. FIGS. 1d to 1 are sectional views illustrating other embodiments.

FIG. 2 is a perspective view, depicting an air gap, of assistance in explaining a method of measuring a magnetic field within an air space of a spherical body of the magnetic field generating device.

A descriptive emphasis will herein be placed on a magnetic field generating device constructed in such a way that magnetic pole pieces (2), (2) each formed with an annular projection (3) on its peripheral edge are, as illustrated in FIG. 1, fixed vis-a-vis with each other to one ends of a pair of permanent magnet assemblies (1), (1) employing Fe-B-R series magnets; rectangular tabular yokes (4) and (5) are fixed to other ends thereof and linked to each other via four lengths of columnar yokes (6) provided at four corners, whereby a static magnetic field is generated within an air gap (7) defined by the magnetic pole pieces (2), (2).

In the air gap (7) of the thus constructed magnetic field generating device, there is set an air space of a spherical body having a predetermined radius r from a center (0) thereof. As depicted in FIG. 2, intensities of the magnetic fields at a plurality of points obtained by equally dividing the circumferences on which a predetermined number-e.g., seven in this case-of horizontal planes (Pa to Pg) intersect the spherical body air space at predetermined angles about an axis Z while these horizontal planes (Pa to Pg) traverse the spherical body, thus examining the variety of the intensities of the magnetic fields on the circumferences of the respective horizontal planes (Pa to Pg). (See FIG. 6)

The portions where the magnetic field intensity is adjusted, i.e. increased or decreased can be set on the respecive magnetic pole pieces (2)(2) correspondingly to a plurality of points on the respective circumferences of the horizontal planes (Pa - Pg), each of the points of which where the magnetic field intensity is measured. As shown in FIG.

1b, either the magnetic material segments (8) or the permanent magnet segments (9) having the magnetizing direction opposite to that of the respective magnetic pole pieces (2)(2) (see SIG. 1c) are arranged on the magnetic pole pieces (2)(2) so as to make the distribution of the magnetic field uniform in accordance with the above -mentioned measurement of the magnetic field intensity.

Further, the permanent magnet pieces (9') (see FIG. 1g) having the same magnetizing direction as that of the permanent magnet assemblies can be arranged in combination with the magnetic material segments (8), because such combined arrangement provides the same effect for adjusting the magnetic field intensity as provided by the arrangement of the magnetic material segments (8) only.

The adjustment of the magnetic field may involve appropriate selections of the number of horizontal planes or the dividing angle in accordance with a required uniformity of the magnetic fields.

The magnetic material segments (8) or the permanent magnet segments (9) secured onto the respective magnetic pole pieces (2), (2) are therefore arranged on a concentric circle, with the result that portions exhibiting a partially higher density of magnetic flux can be diminished, or reversely portions exhibiting a partially lower density thereof can be enlarged without reprocessing the magnetic pole piece (2). Besides, a subtle adjustment of the uniformity becomes practicable.

The permanent magnet segments are bonded to the portions having the partially higher density of the magnetic flux on the magnetic pole piece (2) but may, if necessary, be fitted, as illustrated in FIG. 1(d), in a recessed groove (11).

The foregoing descriptions are related to the embodiments shown in Figs. 1a to 1d and FIG. 1g wherein the annular projection is of a trapezoidal shape in cross-section. Even in the case where the annular projection is of a rectangular shape in cross-section, as shown in FIG. 1f, there can provide the same effect as provided by the embodiments shown in FIGS. 1a to 1d and FIG. 1g. Furthermore, when the magnetic pole pieces (2)(2) are formed convexedly at their central portions (10), as shown in FIG. 1f, in addition to the provision of the annular projection (3), the uniformity of the magnetic field can be further improved.

Configurations of the magnetic material segments or the permanent magnet segments may arbitrarily be adopted. In the case of, e.g., a disk-like shape or a columnar shape, a diameter and a height are properly selectable to make the magnetic field distribution uniform on the basis of the above-mentioned measurement of the magnetic field intensities, whereby the hyperfine adjustment of the magnetic fields can be effected.

The material can also arbitrarily be adopted. Particularly, the material for the permanent magnet segmenrs (9), (9') may preferably be selected relying on the magnetic property of the permanent magnet assemblies (1).

EXAMPLES

FIG. 4 shows results of measuring intensities of the magnetic field acting in directions of the axes X, Y and Z within the air gap (7) in a magnetic field generating device depicted in FIG. 1, wherein a magnetic pole piece formed with a convex projection having a diameter of 300 mm and a height of 1.00 mm and an annular projection having an outside diameter of 1100 mm, an inside diameter of 900 mm and a height of 40 mm is disposed by using an Fe-B-R series permanent magnet exhibiting (BH)max of 35MGOe at a normal temperature, and a confronting distance between the magnetic pole pieces is set to 300 mm.

Moreover, when measuring the magnetic field intensities on the intersecting circumferences of seven horizontal planes (Pa to Pg) with respect to an air space of a spherical body having a diameter of 350 mm within the air gap (7) while these horizontal planes, as shown in FIG. 2, traverse the air space thereof, the results given in FIG. 6 are obtained.

As is obvious from distributions of intensities of the magnetic fields within the air gaps depicted in FIGS. 4 and 6, the intensity is larger in the Y-axis direction (90°, 270°) than in the X-axis direction (0°, 180°) due to an influence of the rectangular yoke.

Based on the distribution of intensities of the magnetic fields within the air space of the spherical body depicted in FIG. 6, the portions for adjusting the magnetic fields on the magnetic pole pieces (2), (2) are determined. Disposed on a concentric circle on each of the magnetic pole pieces (2), (2) are columnar magnetic material segments having a variety of dimensions and made of the same material of the magnetic pole piece or columnar permanent magnet segments having a variety of dimensions and a magnetizing direction opposite to that of the permanent magnet assembly as well as exhibiting the identical characteristics of those of the permanent magnet assembly.

When measuring the magnetic field intensities in the directions of the axes X, Y and Z within the air gap (7) of the magnetic field generating device and also the magnetic field intensities on the intersecting circumferences of the horizontal planes with respect to the air space of the spherical body, there are acquired the results shown in FIGS. 3 and 5.

As is obvious from the distribution of the magnetic field intensity shown in FIGS. 3 and 5, the present invention can diminish not only the influence caused by the configuration of the magnetic pole pieces but also the influence caused by the rectangular yoke so that the magnetic field intensity in the air gap can be made more uniform.

Furthermore, a more precise adjustment of the magnetic field is effected by increasing the number of the horizontal planes, as a result of which the uniformity of the magnetic fields within the air space of the spherical body having a diameter of 350 mm can be reduced down to 50 ppm or under.

Although the illustrative embodiments have been described in detail with reference to the accompanying drawings, it is to be understood that the present invention is not limited to those precise embodiments. Various changes or modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the invention.

Claims

1. A magnetic field generating device for MRI having a pair of permanent magnet assemblies disposed vis-a-vis with each other to form an air gap therebetween, yokes for magnetically linking said pair of permanent magnet assemblies and magnetic pole pieces fixed to air-gap-confronting surfaces of said permanent magnet assemblies to thereby generate magnetic fields within said air gap, the magnetic field generating device characterized in that a plurality of magnetic material segments for adjusting the magnetic fields and/or a plurality of permanent magnet segments for adjusting the magnetic fields and having the same magnetizing direction as that of the permanent magnet assemblies are arranged in the form of a circle or concentrically on the surface of each of the magnetic pole pieces, the surface of which confronting the air gap.

2. The device as set forth in Claim 1, wherein respective peripheral edges of said confronting surfaces of said magnetic pole pieces are formed with annular projections.

3. The device as set forth in Claim 2, wherein said annular projection assumes a trapezoidal or rectangular configuration in section.

4. The device as set forth in claim 2, wherein convex projections are formed at the centers of said confronting surfaces of said magnetic pole pieces.

5. The device as set forth in Claim 2, wherein said each of said magnetic material segments for adjusting the magnetic fields assumes a disk-like or columnar shape.

6. A magnetic field generating device for MRI, comprising:

a pair of permanent magnet assemblies disposed vis-a-vis with each other to form an air gap therebetween;

yokes for magnetically linking said pair of permanent magnet assemblies; and

magnetic pole pieces fixed to air-gap-confronting surfaces of said permanent magnet assemblies to thereby generate magnetic fields within said air gap, characterized in that a plurality of magnetic field adjusting permanent magnet segments having a magnetizing direction opposite to that of said permanent magnet assemblies are disposed on the same circle or a concentric circle on said air-gap-confronting surface of said magnetic pole piece.

7. The device as set forth in Claim 8, wherein respective peripheral edges of said confronting surfaces of said magnetic pole pieces are formed with annular projections.

8. The device as set forth in Claim 7, wherein each of said annular projections assumes a trapezoidal or rectangular configuration in section.

9. The device as set forth in Claim 7, wherein convex projections are formed at the centers of said confronting surfaces of said magnetic pole pieces.

10. The device as set forth in Claim 6, wherein each of said permanent magnet segments for adjusting the magnetic fields assumes a disk-like or columnar shape.

11. The device as set forth in Claim 6, wherein said permanent magnet segments for adjusting the magnetic fields are fitted in recessed grooves furrowed in said confronting surfaces of said magnetic pole pieces.

12. A magnetic field generating device for MRI, comprising:

a pair of permanent magnet assemblies disposed vis-a-vis with each other to form an air gap therebetween;

yokes for magnetically linking said pair of permanent magnet assemblies; and

magnetic pole pieces fixed to air-gap-confronting surfaces of said permanent magnet assemblies to thereby generate magnetic fields within said air gap, characterized in that a plurality of magnetic material segments for adjusting magnetic fields and a plurality of magnetic field adjusting permanent magnet segments having a magnetizing direction opposite to that of said permanent magnet assemblies are disposed on the same circles or concentric circles on air-gap confronting surfaces of said magnetic pole pieces.

13. The device as set forth in Claim 12, wherein respective edges of said confronting surfaces of said magnetic pole pieces are formed with annular projections.

14. The device as set forth in Claim 13, wherein each of said annular projections assumes a trapezoidal or rectangular configuration in section.

15. The device as set forth in Claim 13, wherein convex projections are formed at the centers of said confronting surfaces of said magnetic pole pieces.

16. The device as set forth in Claim 12, wherein each of said magnetic field adjusting magnetic material segments and permanent magnet segments assumes a disk-like or columnar shape.

17. The device as set forth in Claim 12, wherein said magnetic field adjusting permanent magnet segments are fitted in recessed grooves furrowed in said confronting surfaces of said magnetic pole pieces.

Fig. 1a

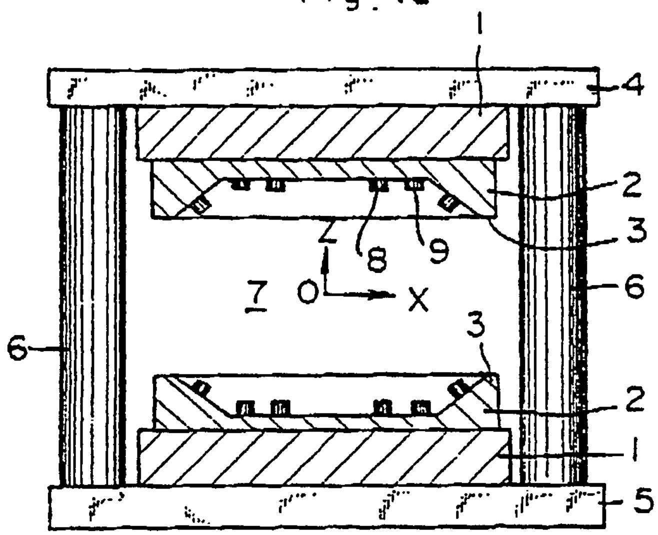
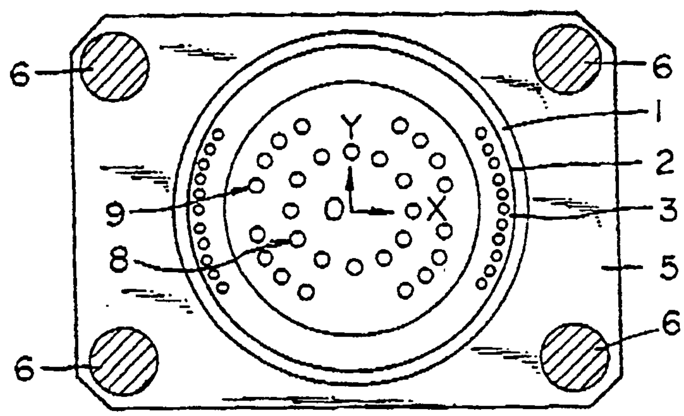


Fig. 1b



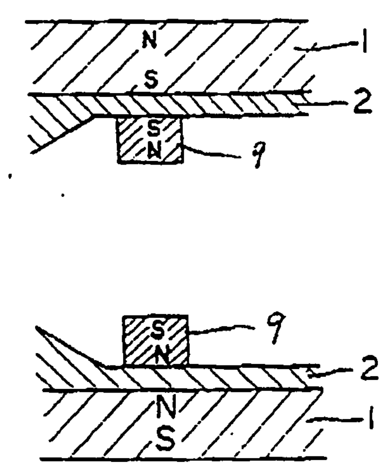


Fig. 1c

Fig. 1d

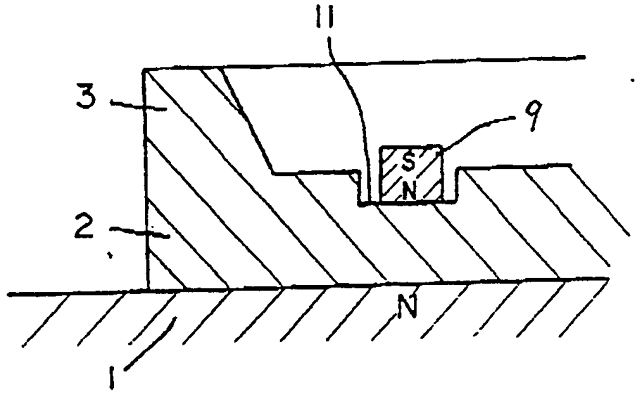


Fig. 1e

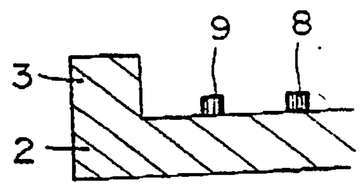
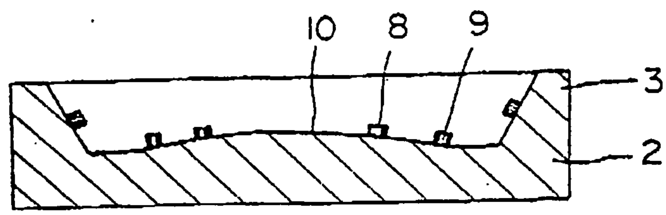


Fig. 1f



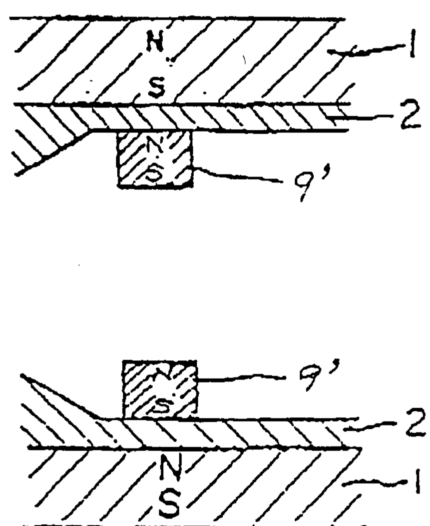


Fig. 1 g

Fig. 2

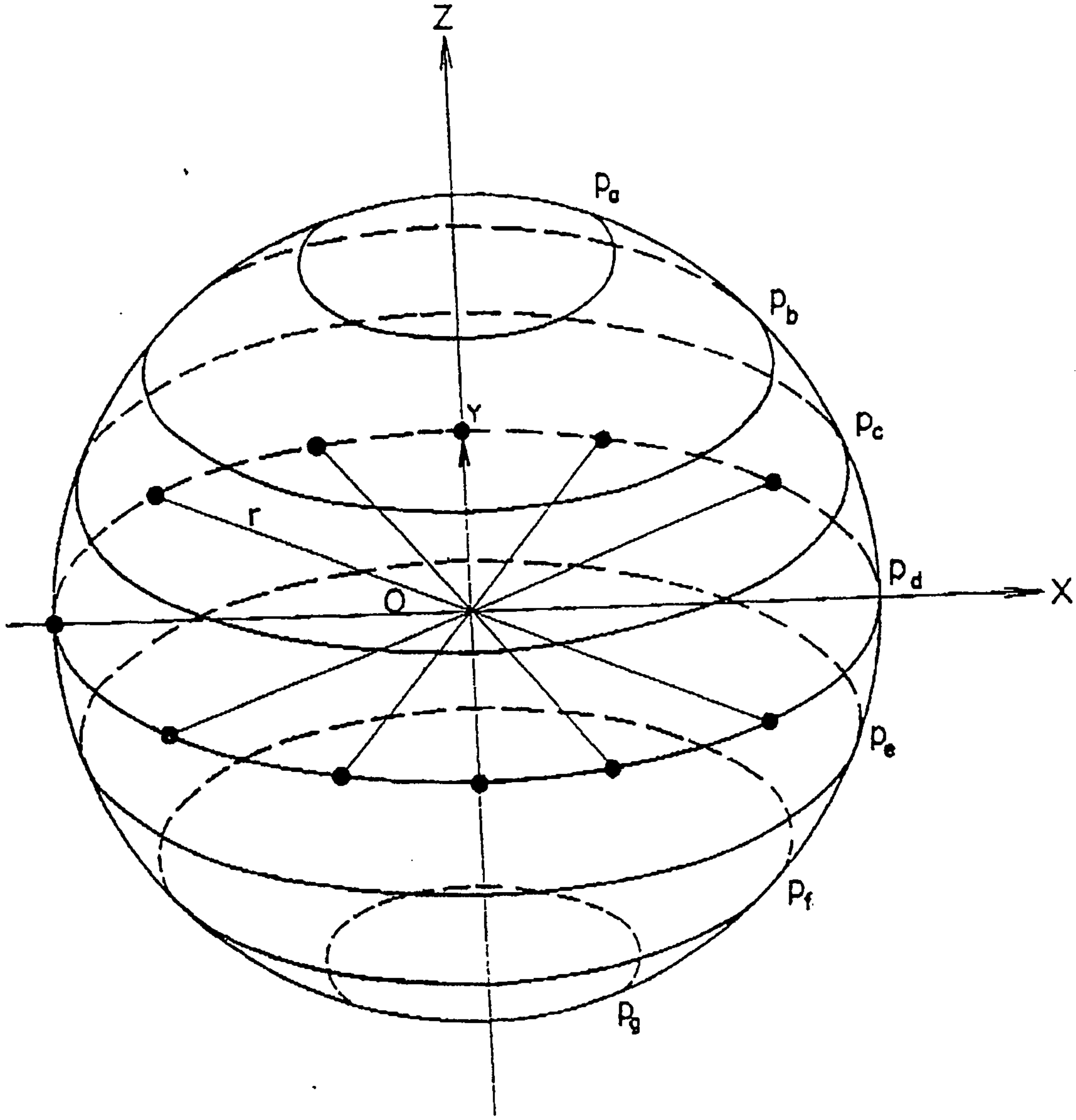


Fig. 3

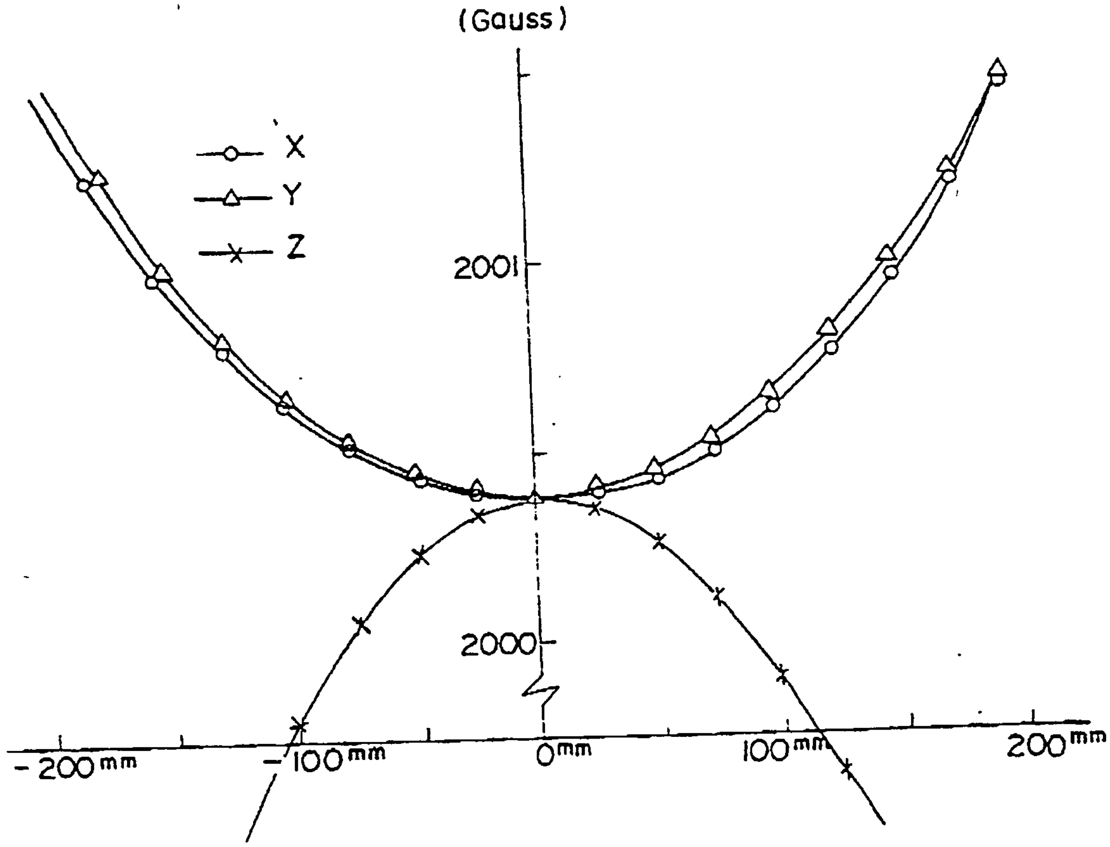


Fig. 4

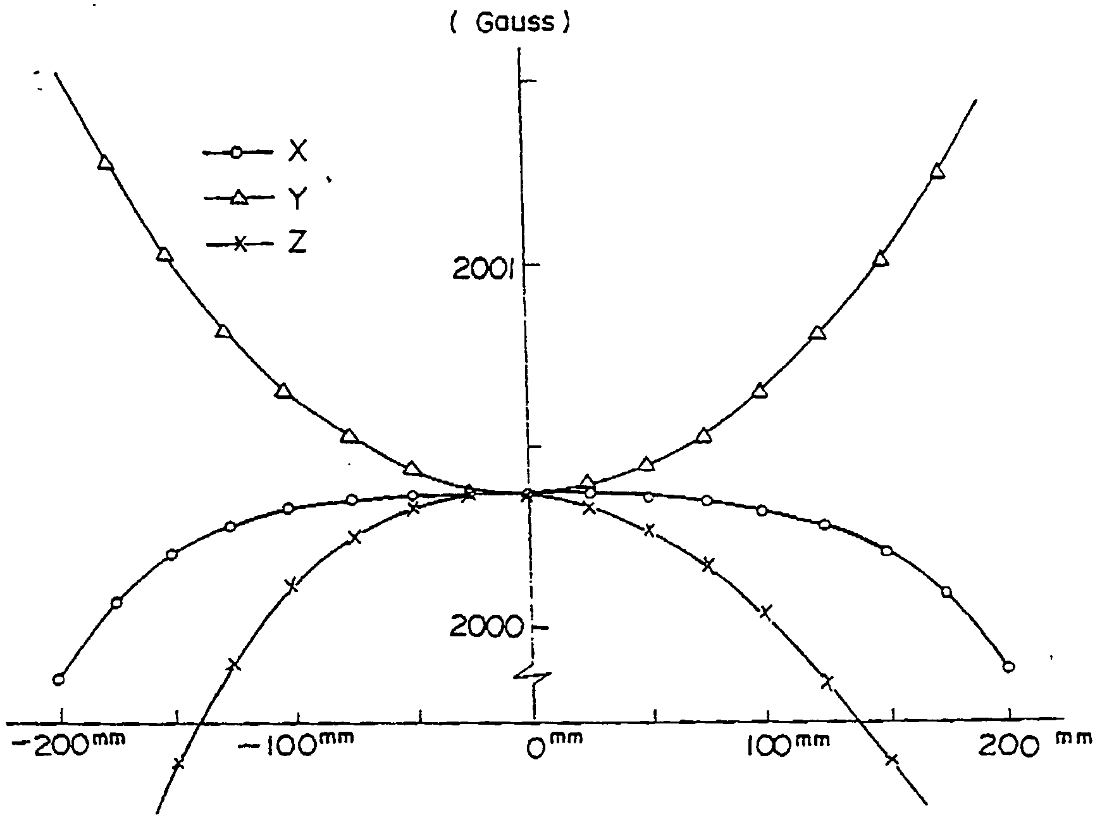
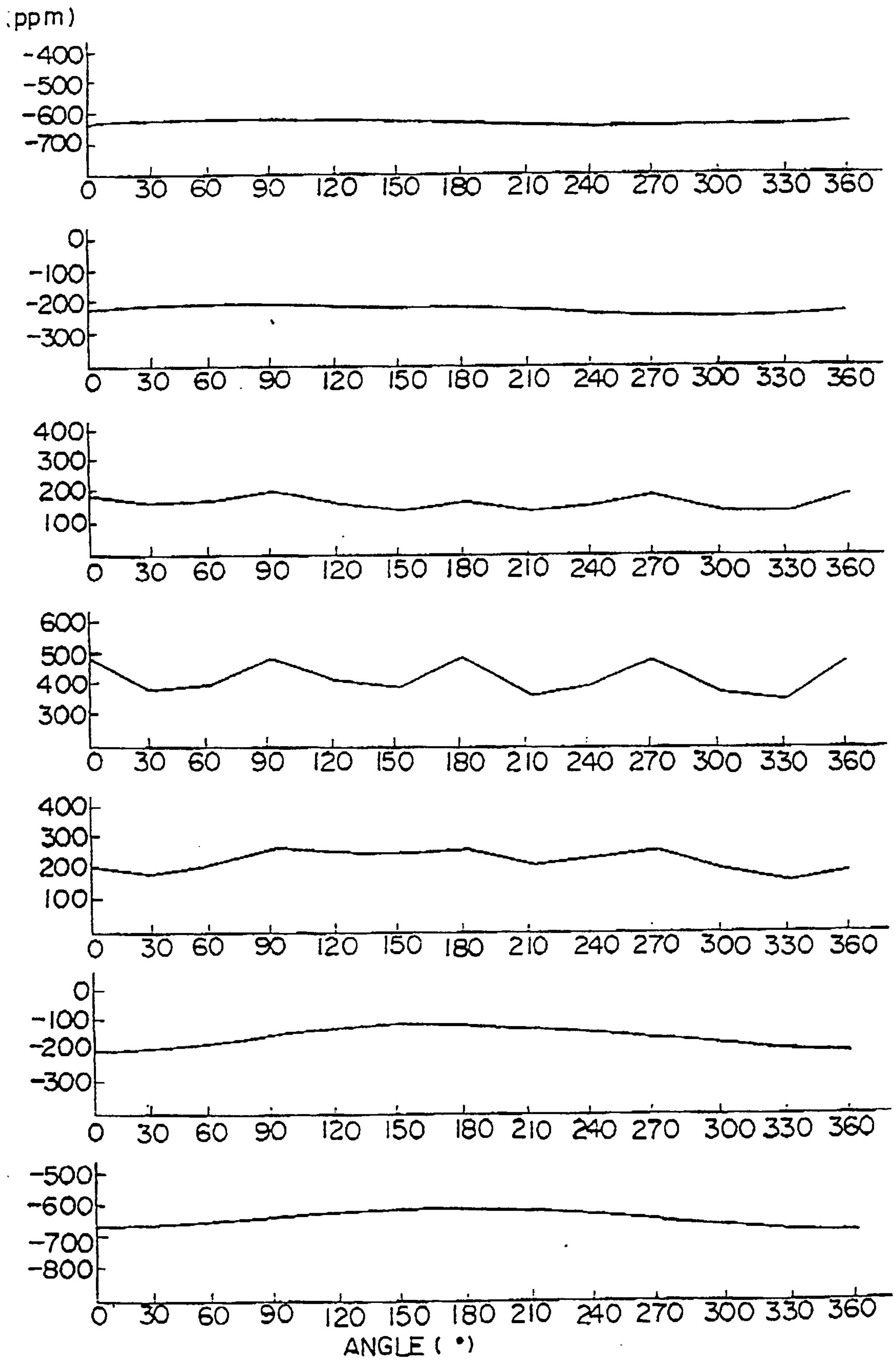


Fig. 5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-600
-700
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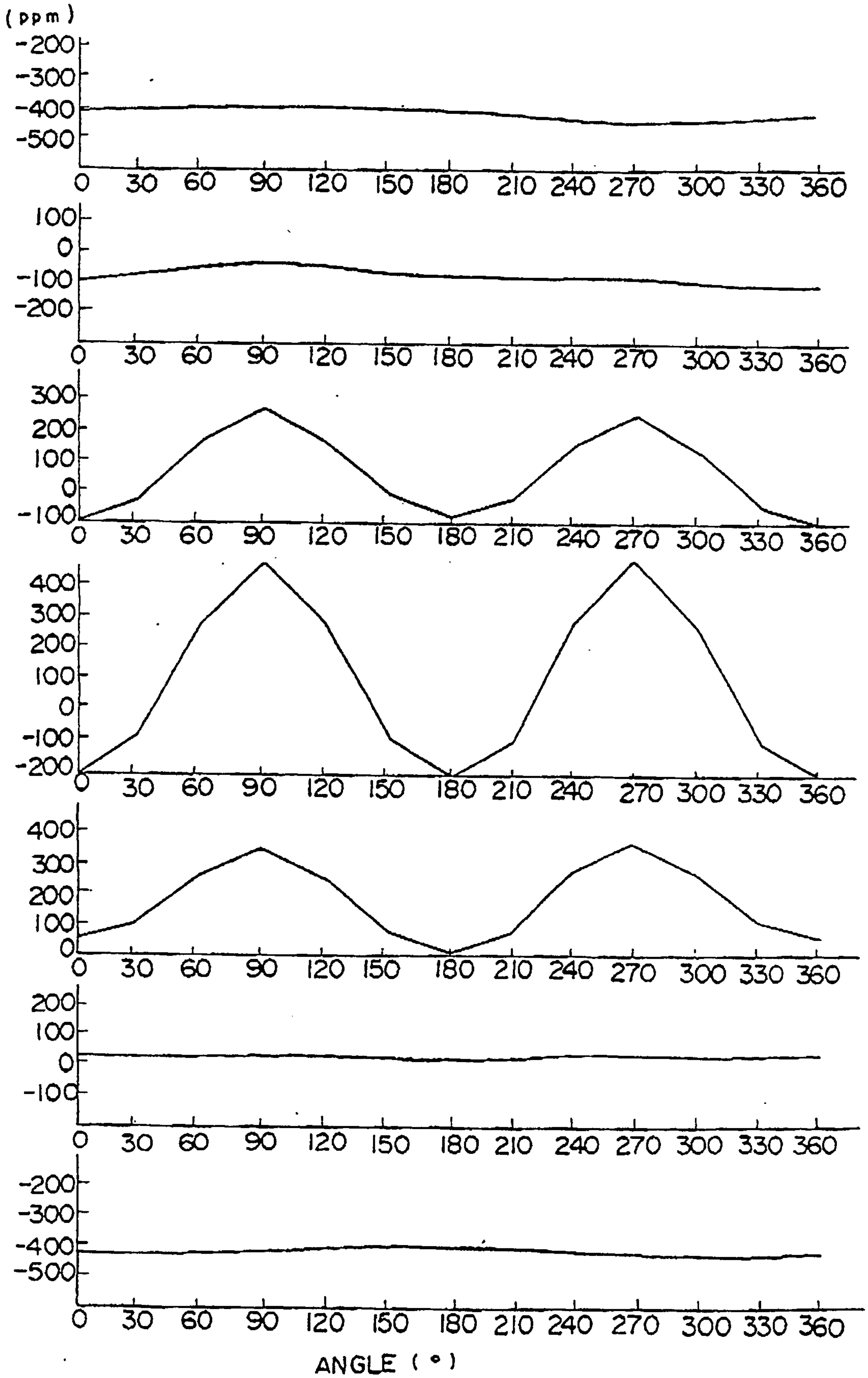
-100
-200
-300
400
300
200
100
600
500
-800
ANGLE (°)

Fig. 6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0
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-200
0 30 60 90 120 150 180 210 240 270 300 330 360
ANGLE (°)